

**The George W. Woodruff School of Mechanical Engineering
Georgia Institute of Technology**

Fluid Film Lubrication in Chemical Mechanical Polishing

*by Gary S.H. Ng, Len Borucki, C. Fred Higgs, III,
Inho Yoon, Andres Osorno, Steven Danyluk*

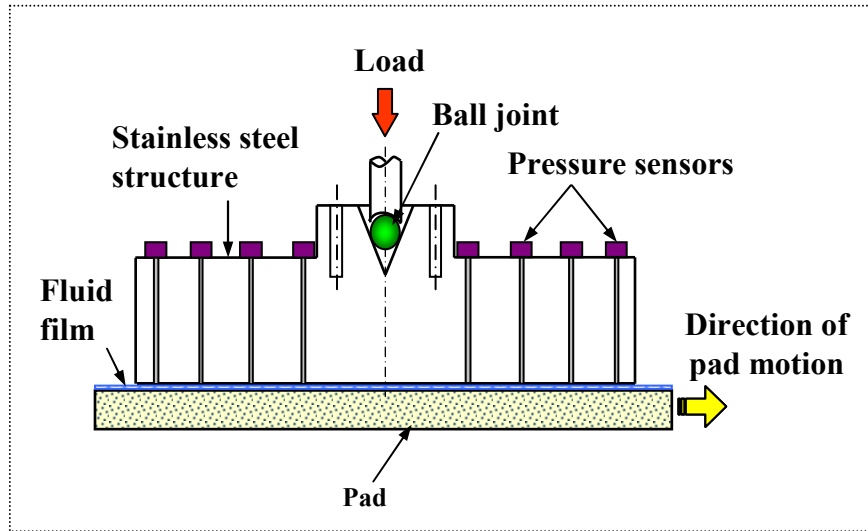
4 Feb 2004



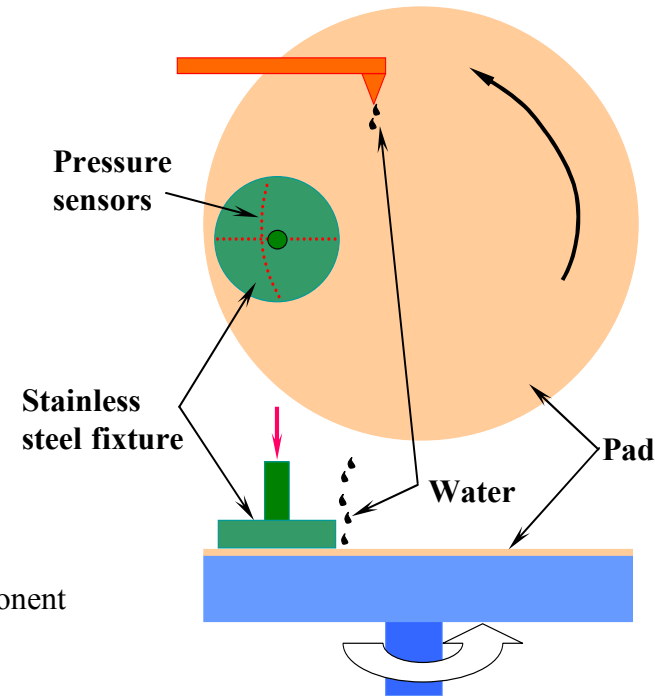
Outline

- Background and Objectives
- Two-Dimensional Pressure Mapping
- Fixture Tilt Measurements
- Wafer Bending
- Tilt-Suction Modeling
- Conclusions
- Acknowledgements

Subambient Fluid Pressure Measurement

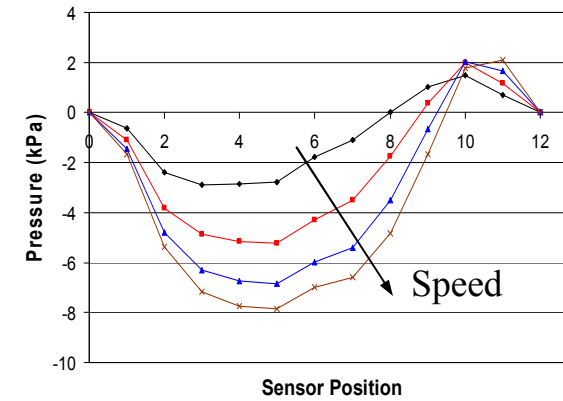
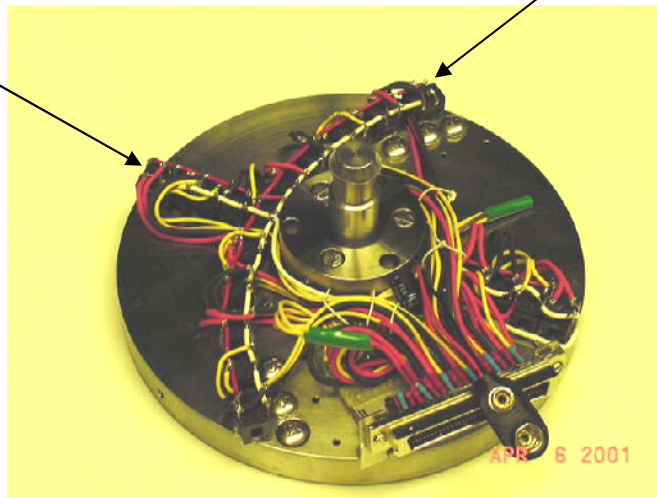


6-inch diameter stainless steel pressure measurement fixture



Radial-component pressure sensors

Tangential-component pressure sensors



Why 2D-Pressure Mapping?

- 1D-mapping is insufficient to fully understand the phenomenon of sub-ambient fluid pressures in a fixture sliding against an elastic pad

Why Tilt Measurement?

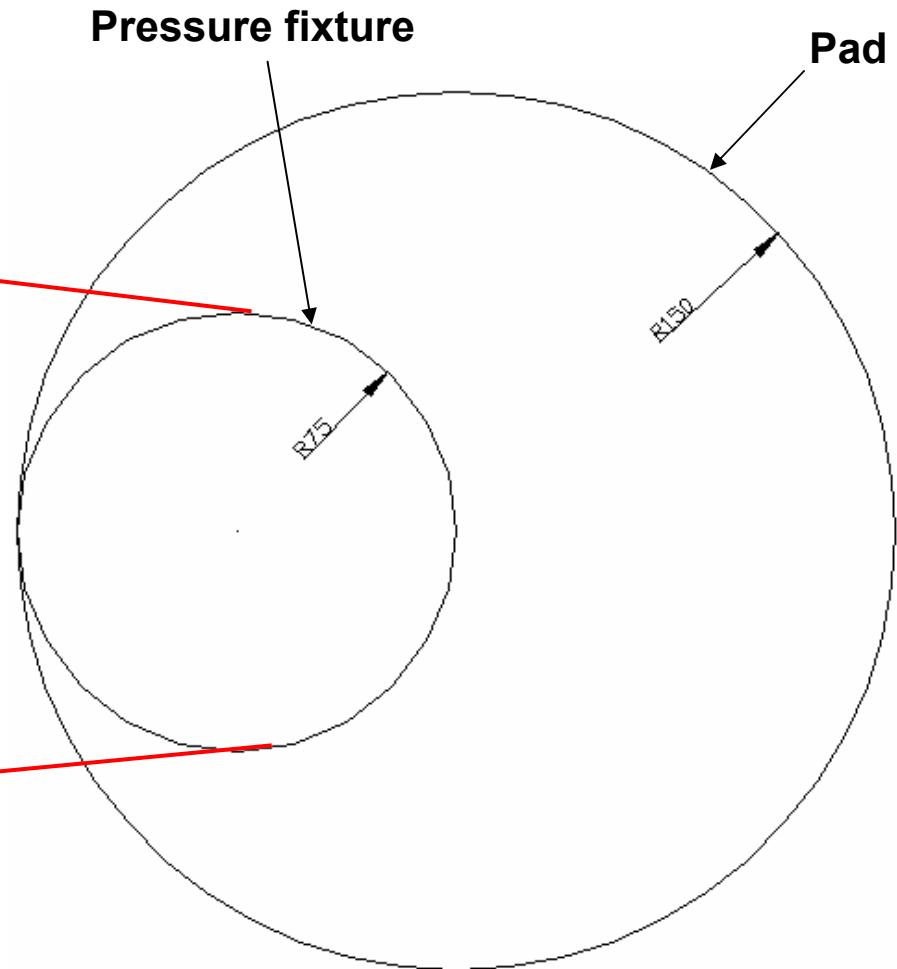
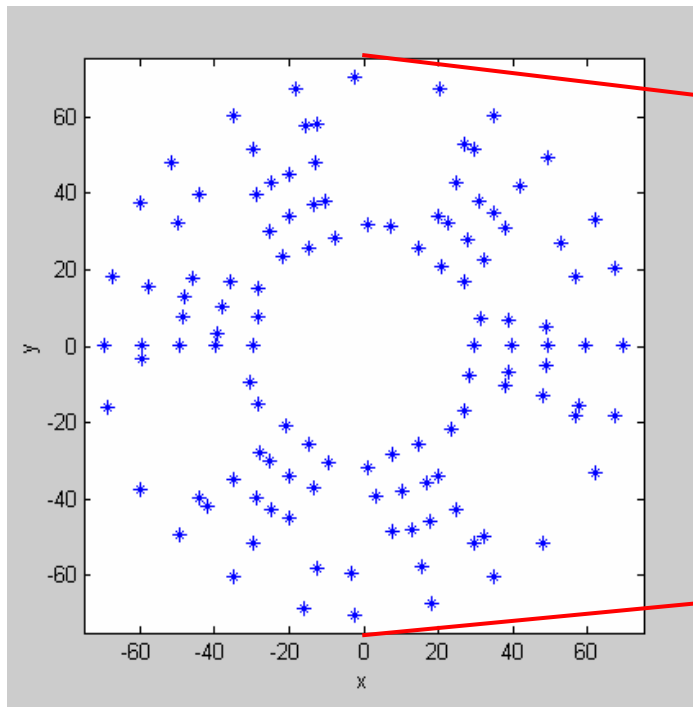
- Previous 1D model based on K.L. Johnson's "sliding punch" model is inadequate when applied to the 2D case
- There is a way to re-create the experimental 2D-pressure map if the fixture is tilted in a certain way

Objectives

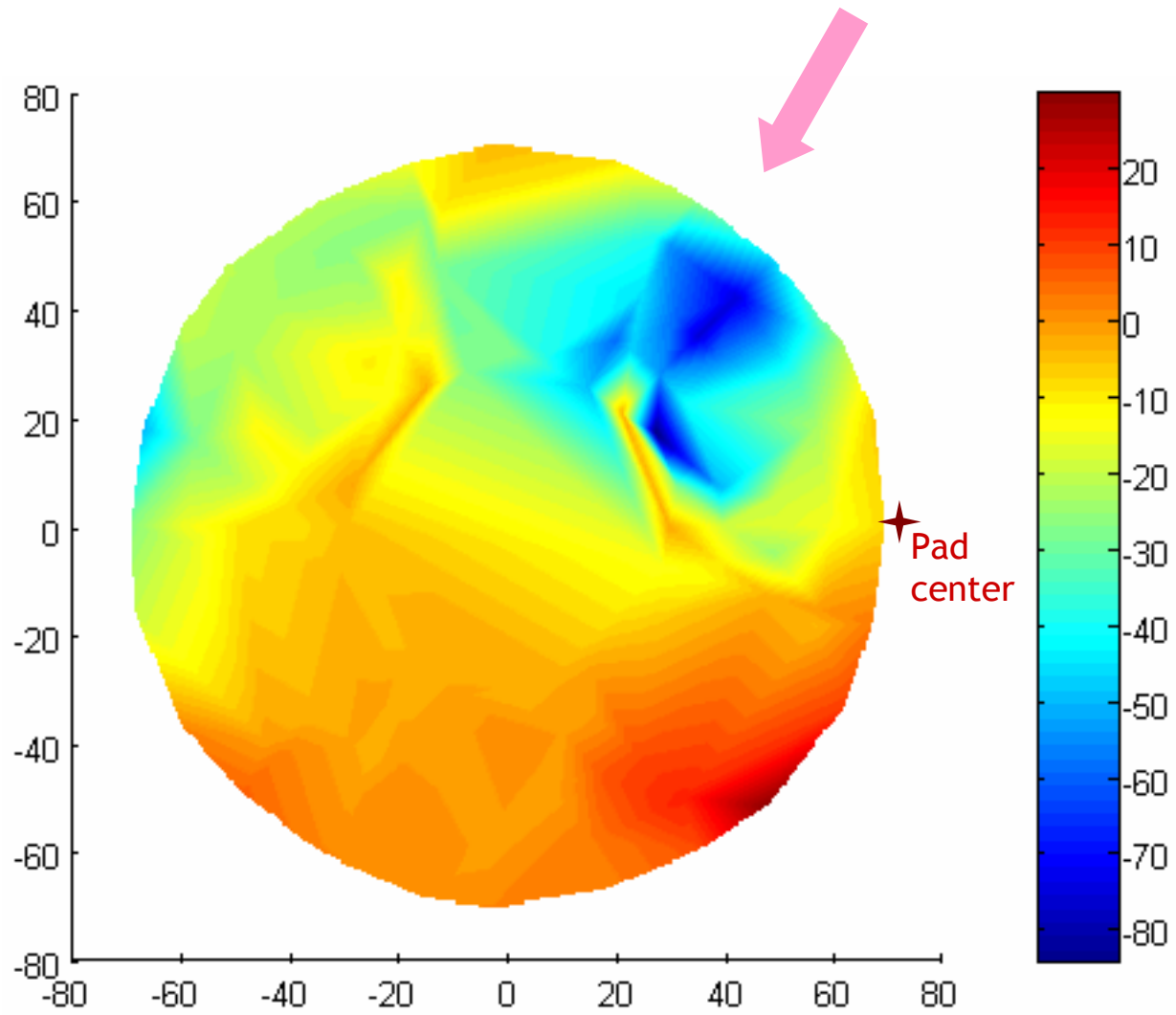
- Map out the fluid pressure between the fixture and the pad
- Measure the orientation and displacement of the fixture under dynamic conditions
- Show evidence that the conclusions are unchanged when a wafer and carrier film are used.
- Model the fluid pressure map base on the geometry of the gap between fixture and pad

Layout for Interfacial Fluid Pressure Mapping

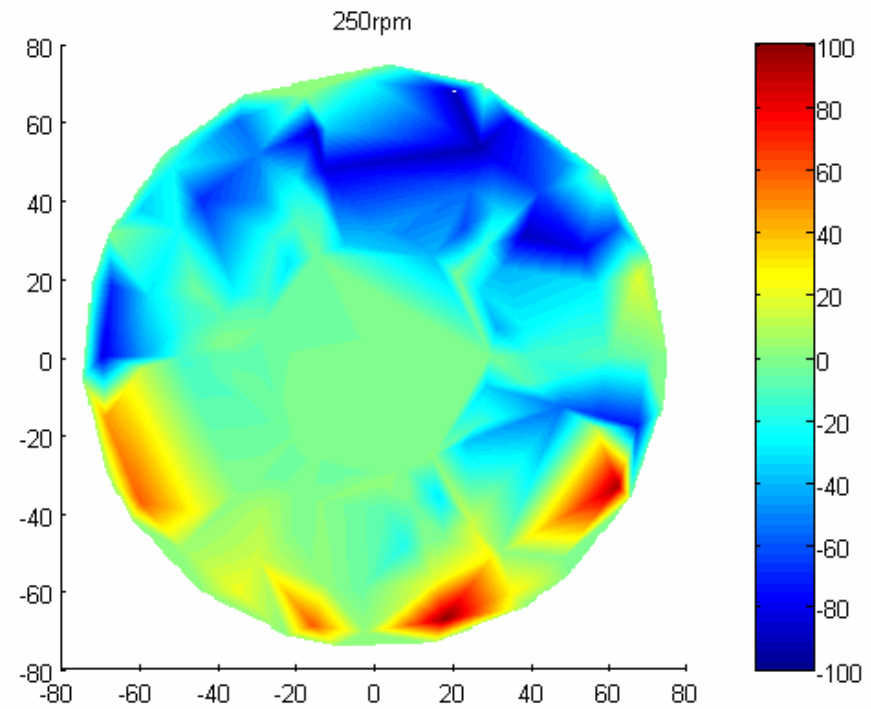
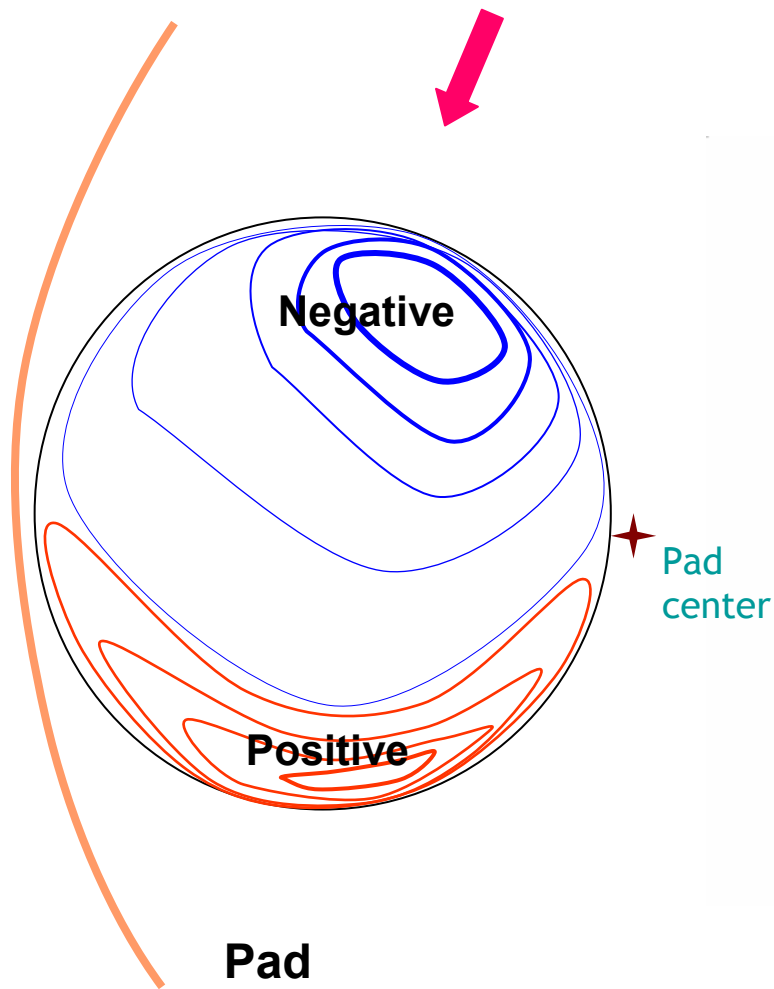
120 points data spread for pressure mapping



Pressure Mapping Results

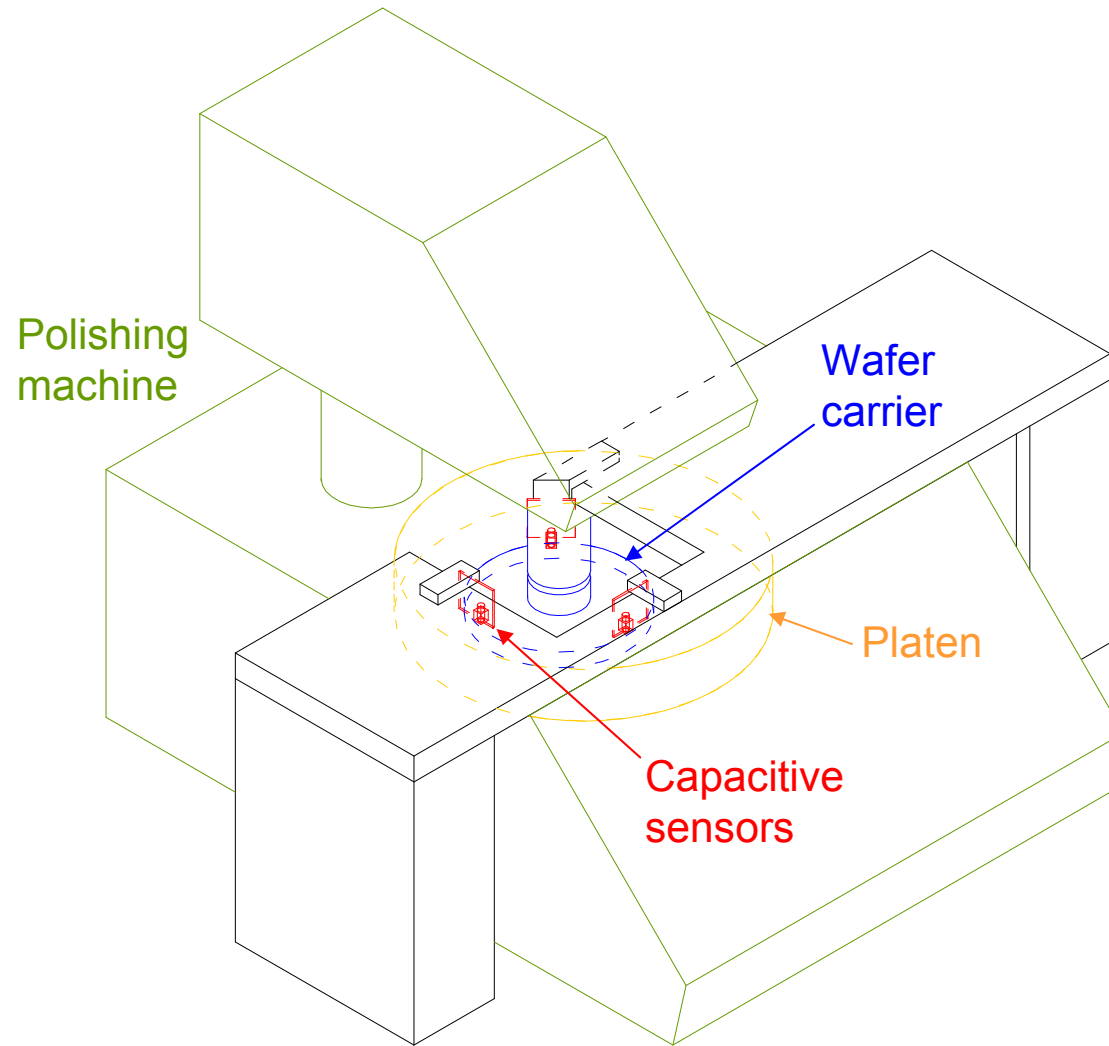


Pressure Map with Pad Speed

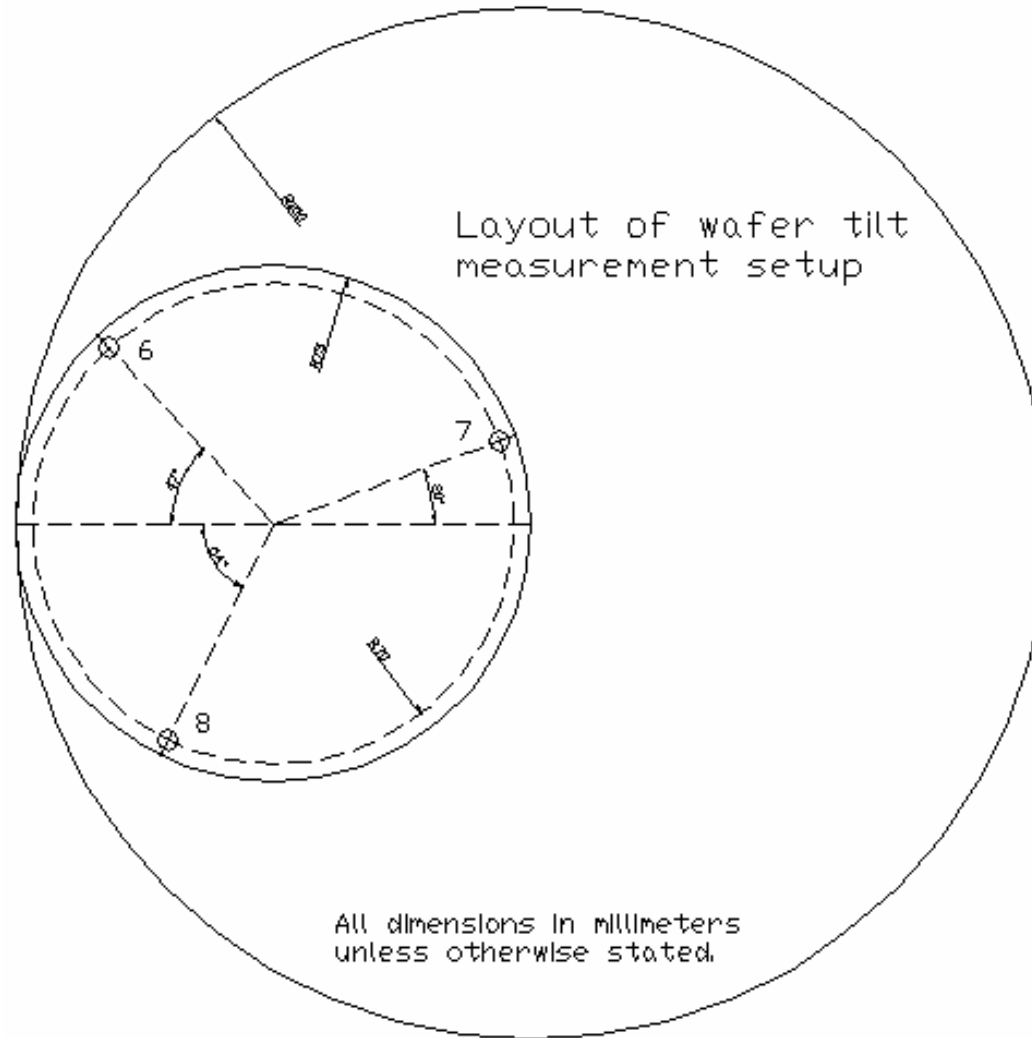


Fixture Tilt

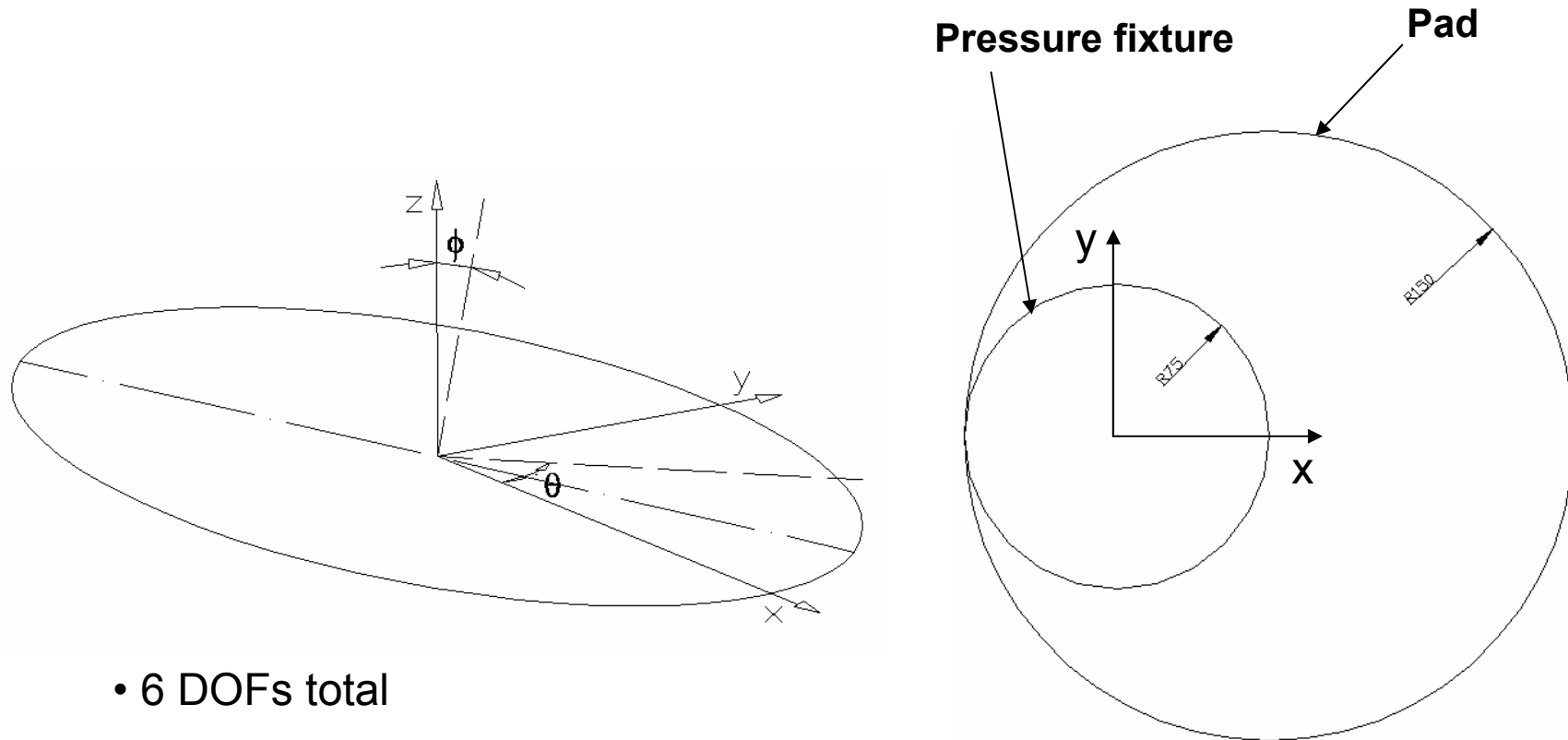
Schematic of Tilt Setup



Experimental Layout

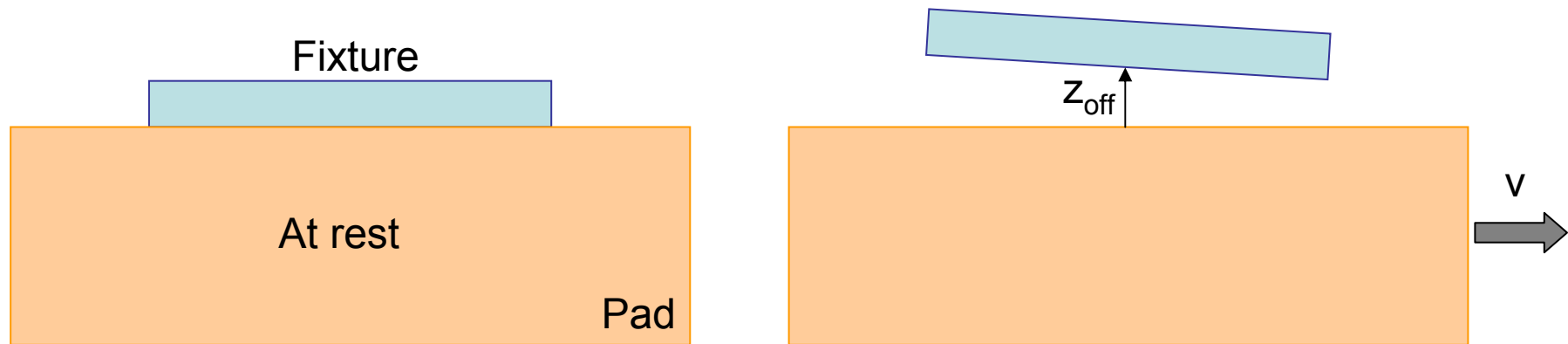


Definition of Tilt Angles



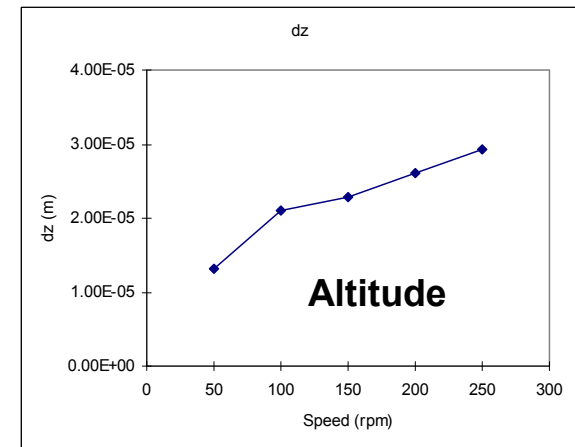
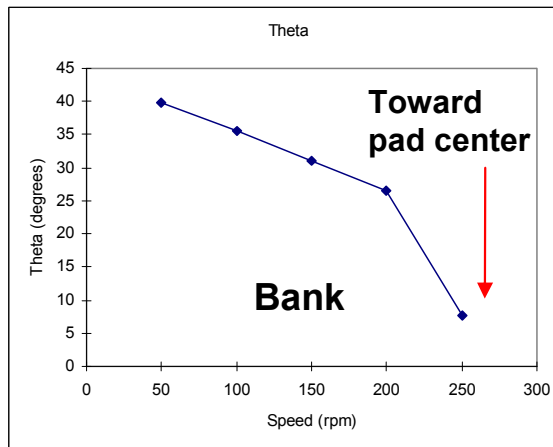
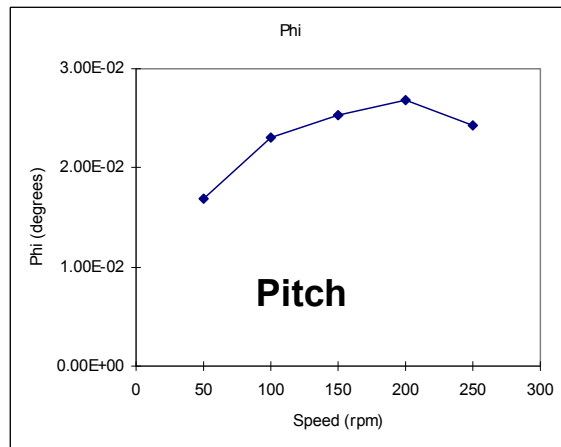
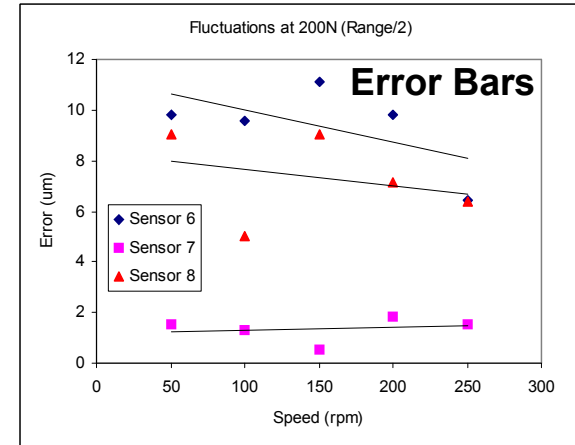
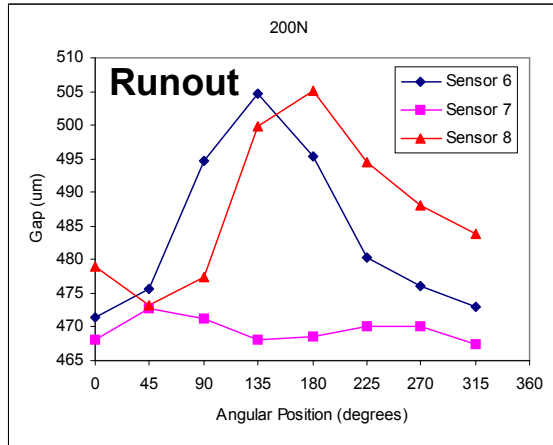
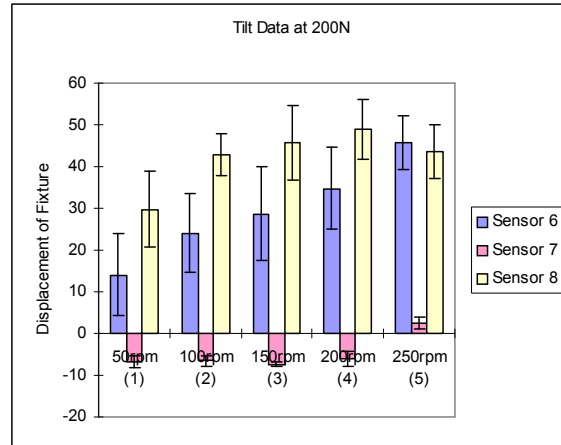
- 6 DOFs total
- constrained in x, y displacements and rotation about z-axis
- 3 DOFs to describe orientation and movement: phi (elevation angle), theta (azimuth angle) and z_{off} (fly height)

Fixture Fly Height or Altitude



Fixture Tilt (200N)

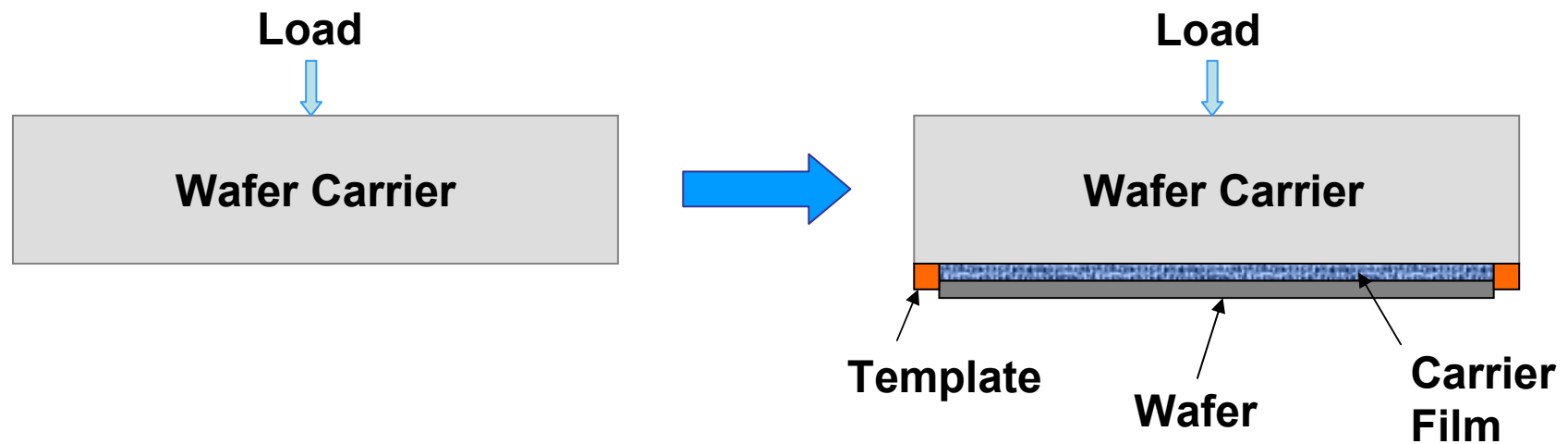
With increasing speed, the fixture is observed to pitch down and bank markedly toward the pad center. The altitude or fly height also increases.



Is the tilt still there in the actual
CMP configuration with
a wafer and carrier film?

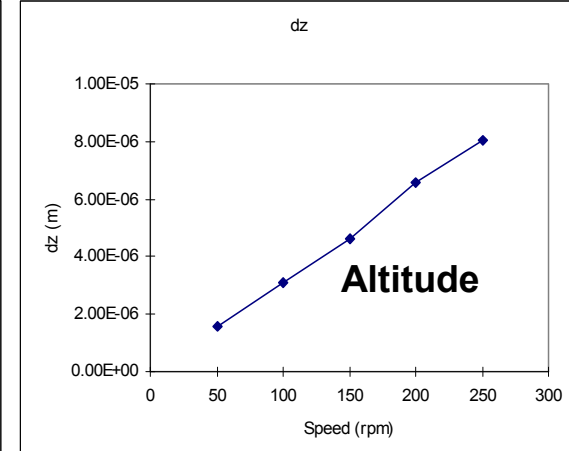
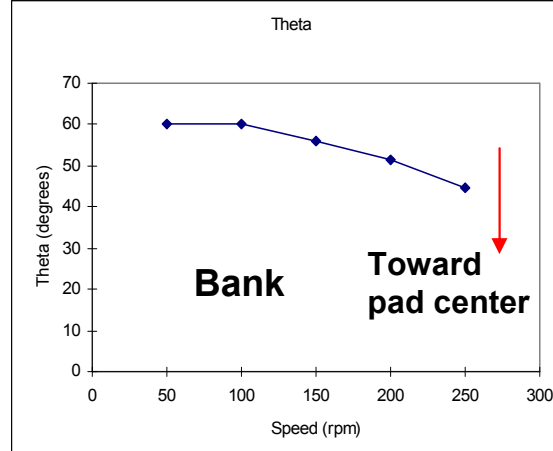
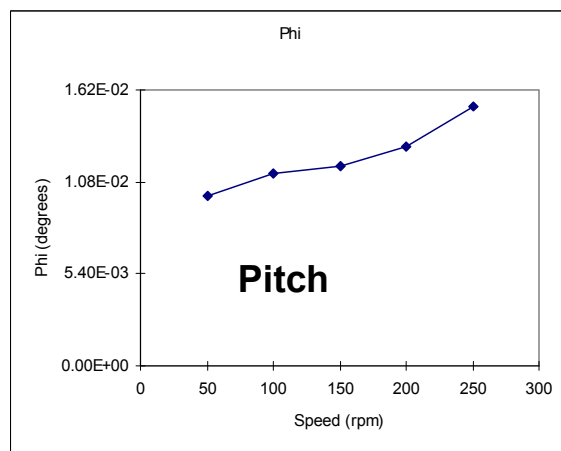
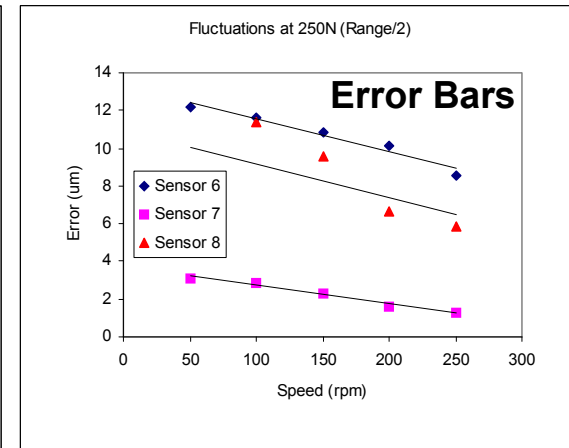
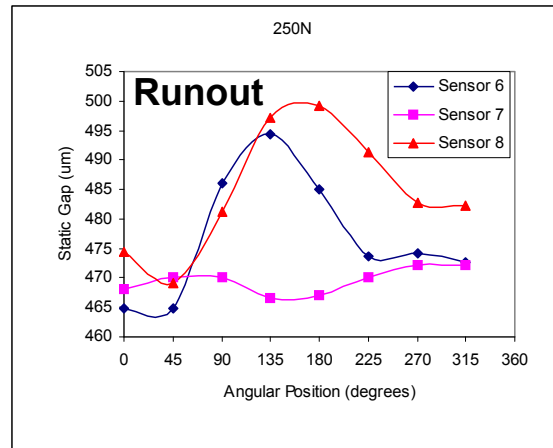
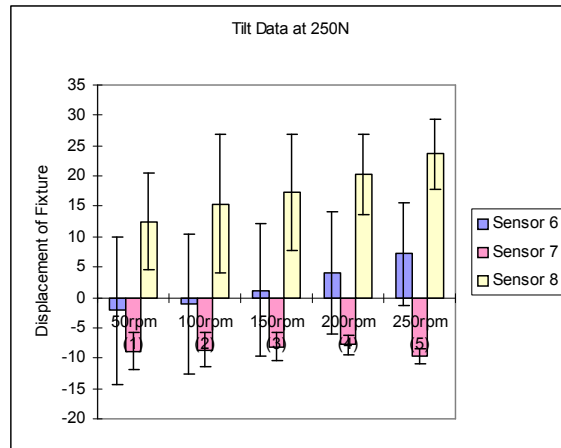
Fixture Tilt with Wafer, Carrier Film and Retaining Ring

Details of the Wafer Carrier



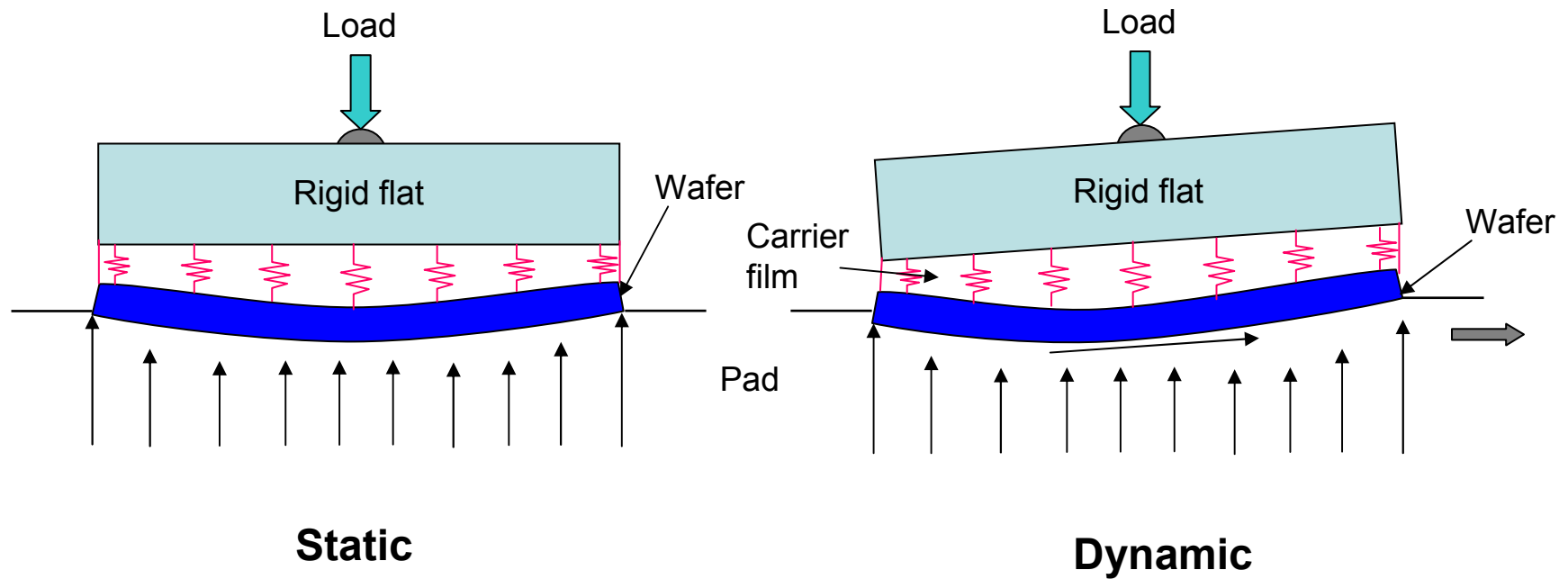
Fixture Tilt with Wafer (250N)

The same trends are observed when a wafer and carrier film are used.



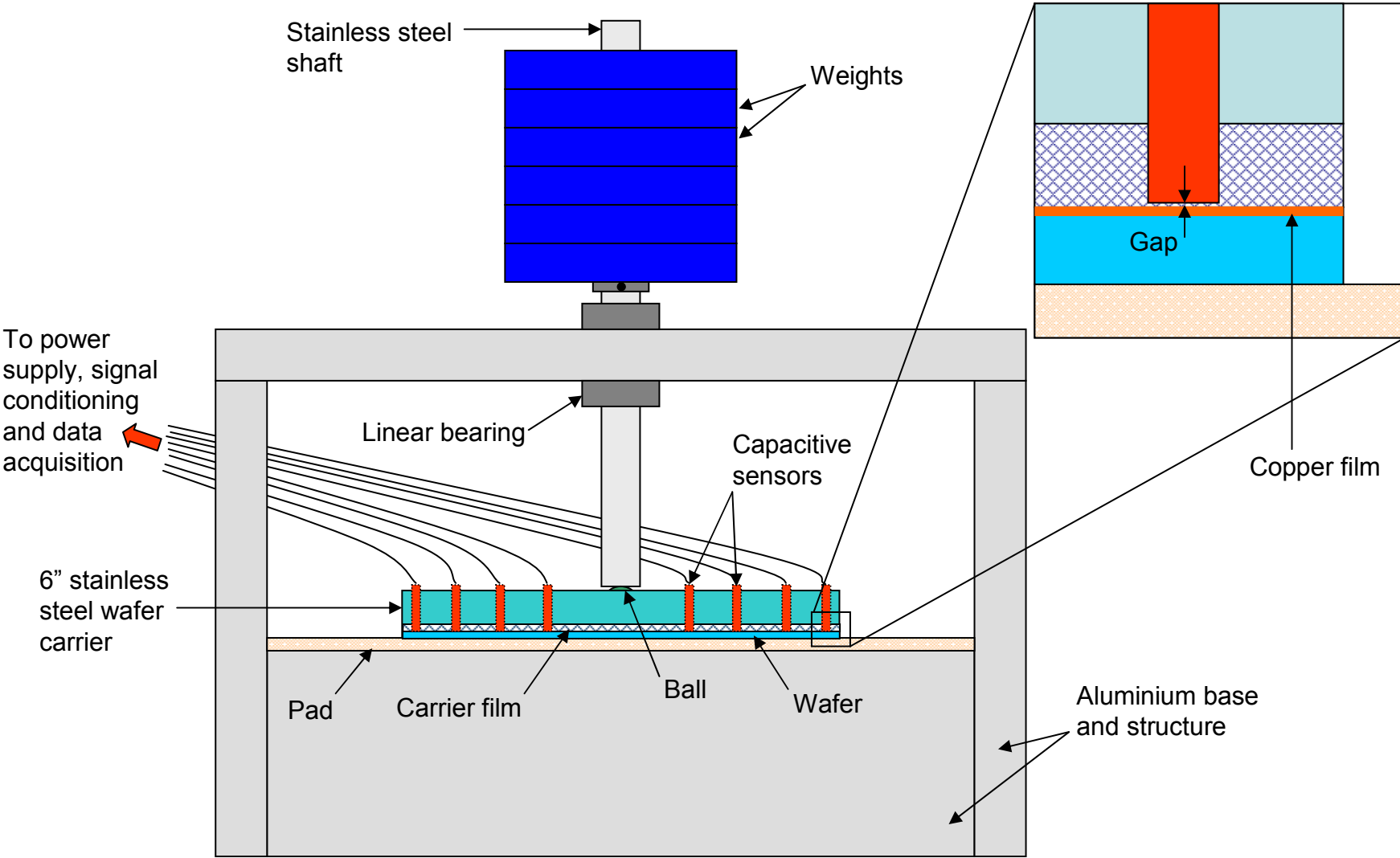
How much does the wafer bend, or tilt with respect to the wafer carrier?

Static and Dynamic Wafer Bending



Static Wafer Bending

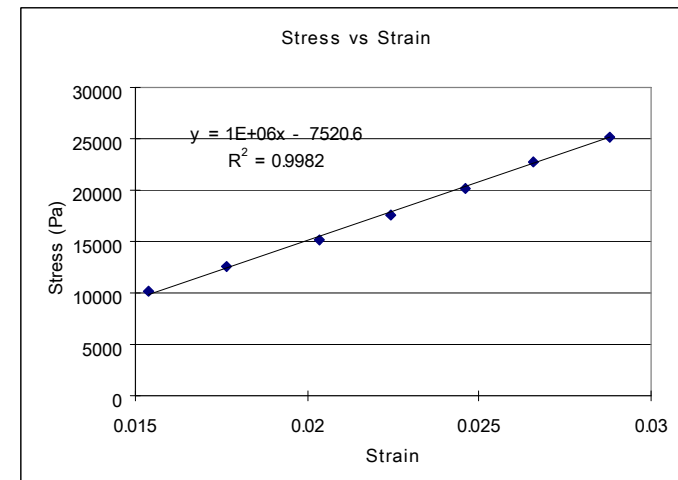
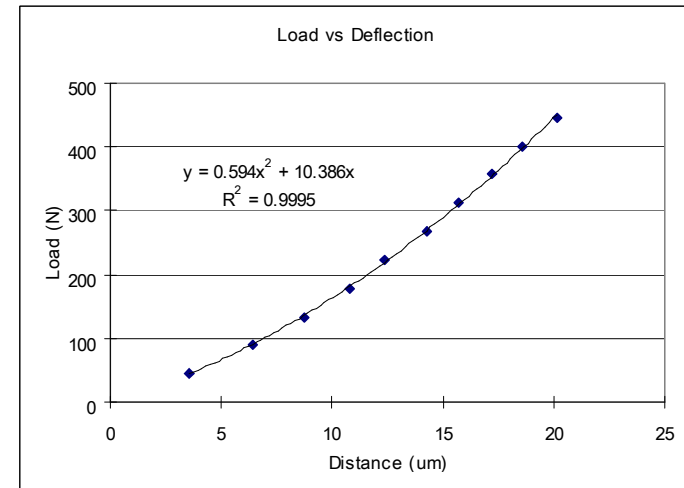
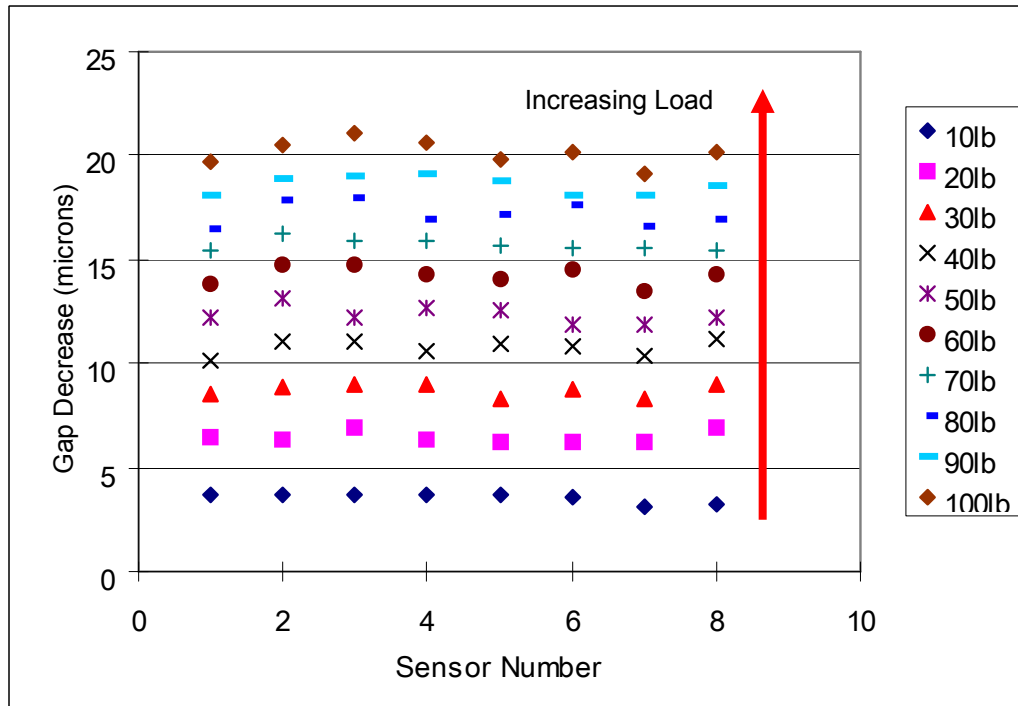
Schematic Diagram of Static Compression Setup (Sensors-in-wafer-carrier configuration)



Wafer Profile against Granite Flat

Showing the response of the wafer when a carrier film alone is used ...

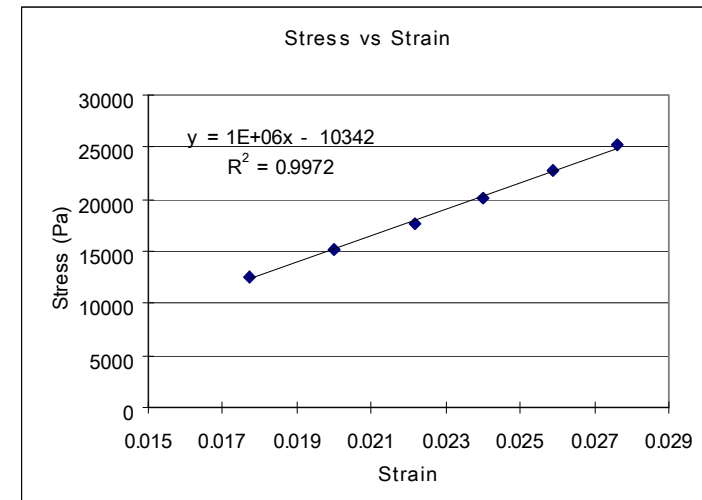
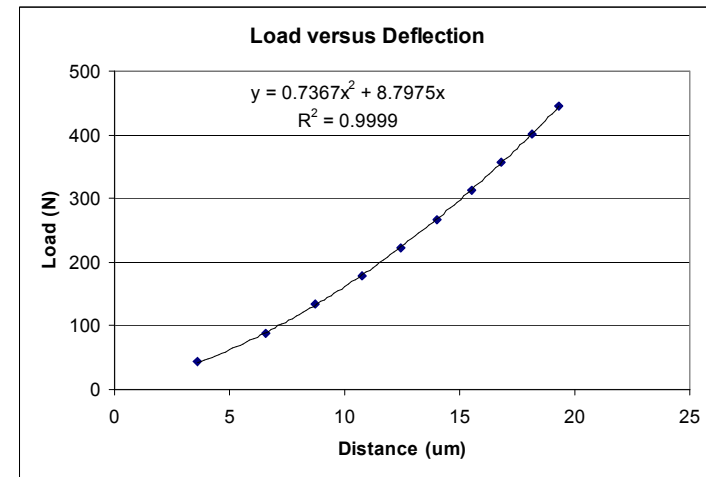
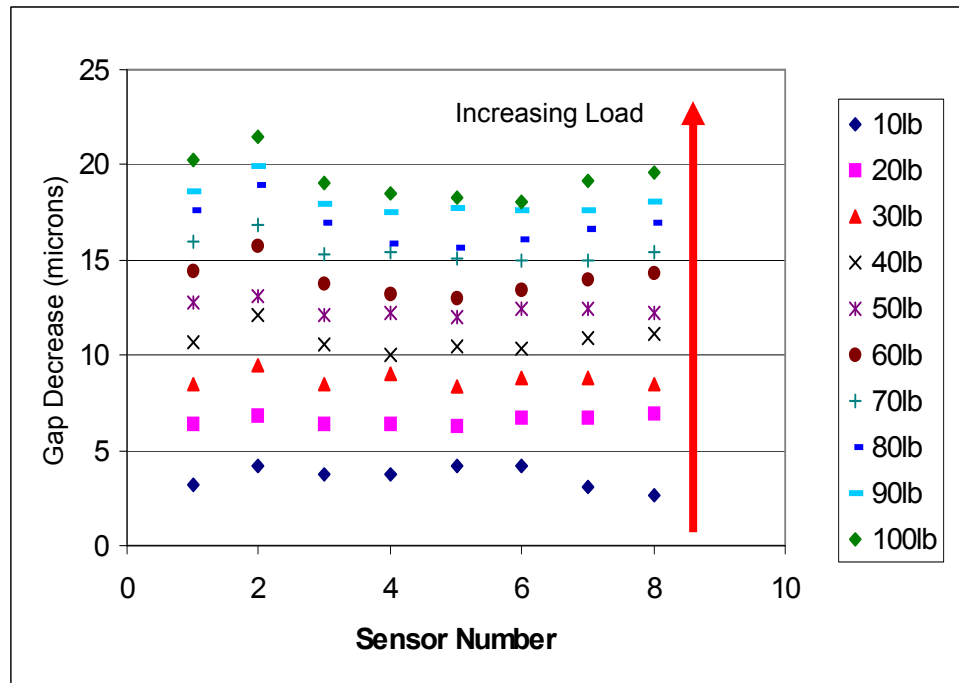
Conclusion: The wafer remains flat under static loading.



Wafer Profile for Pad Soaked for 3 Hours

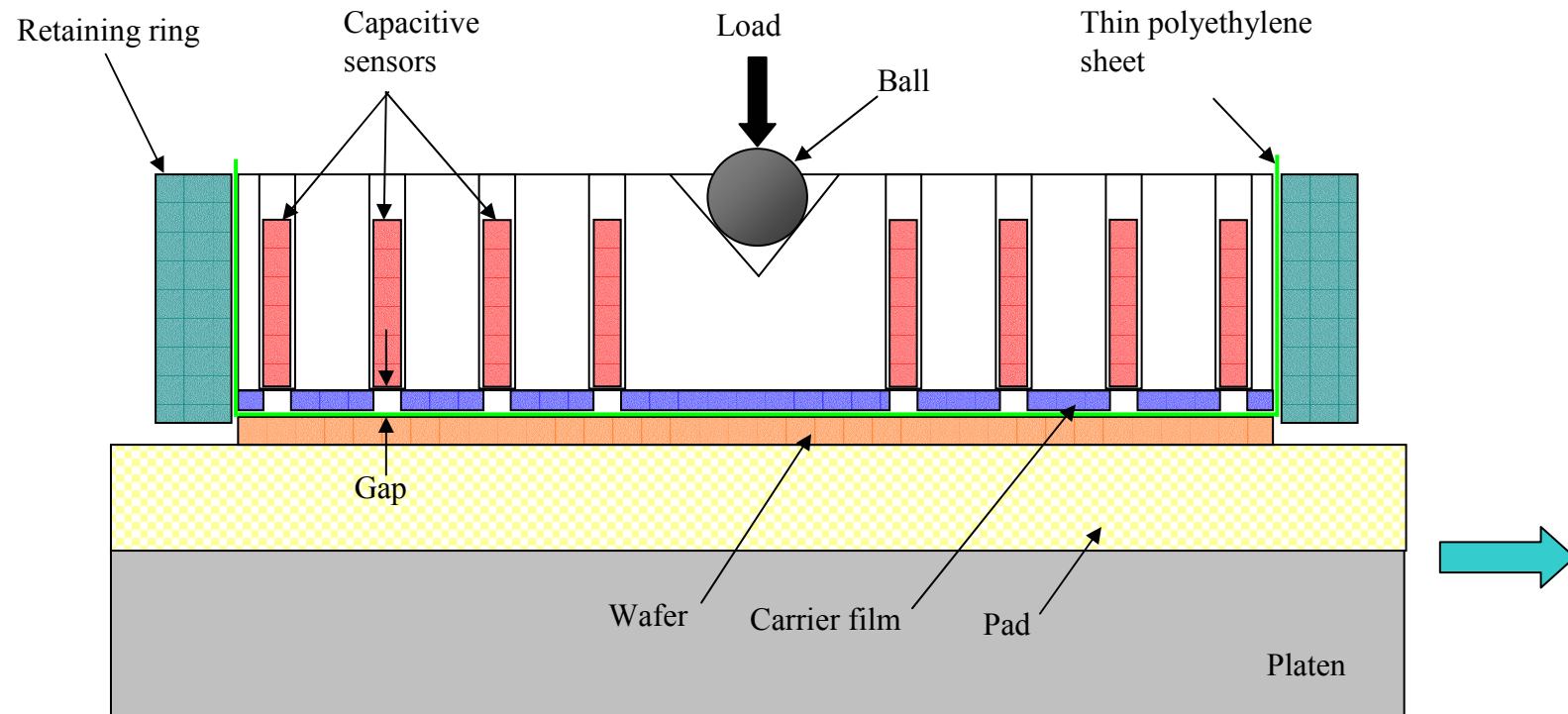
Showing the wafer response when both a carrier film and wet pad are present.

Conclusion: The wafer is still flat under static loading.



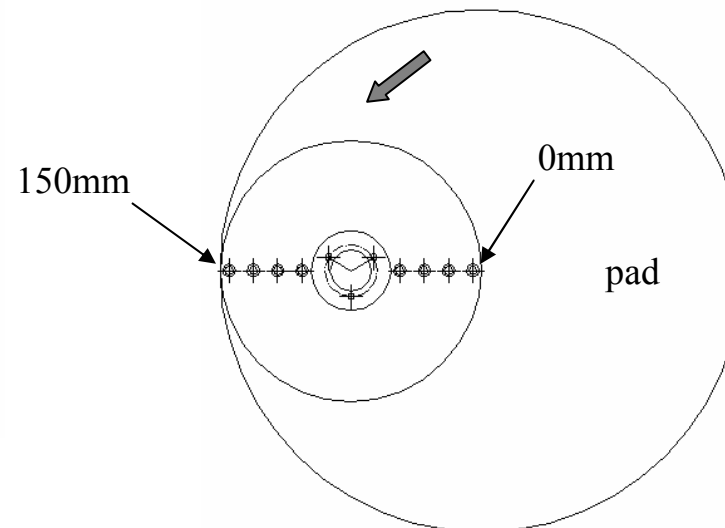
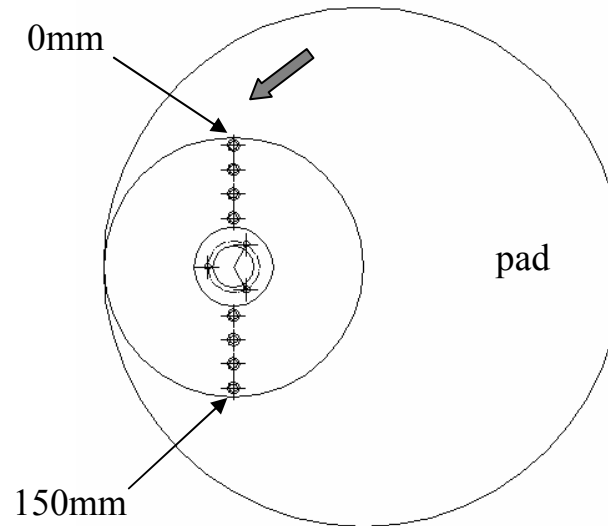
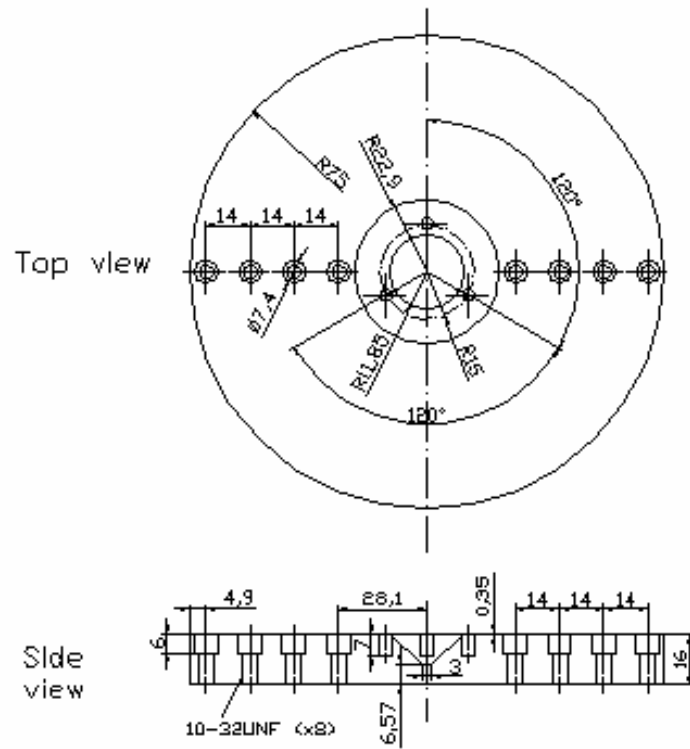
Dynamic Wafer Bending

Wafer Bending Fixture For Dynamic Measurements



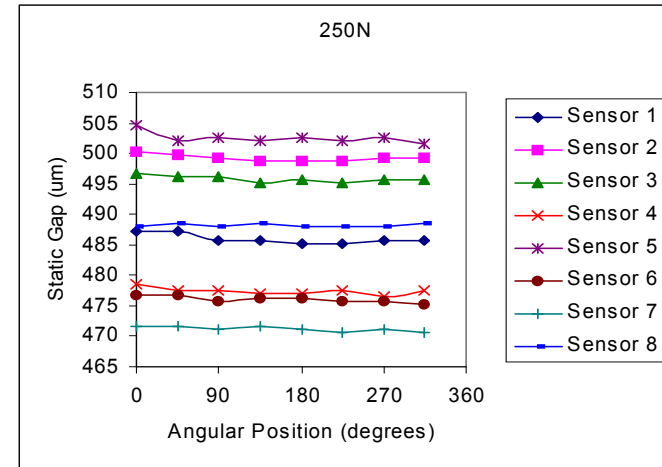
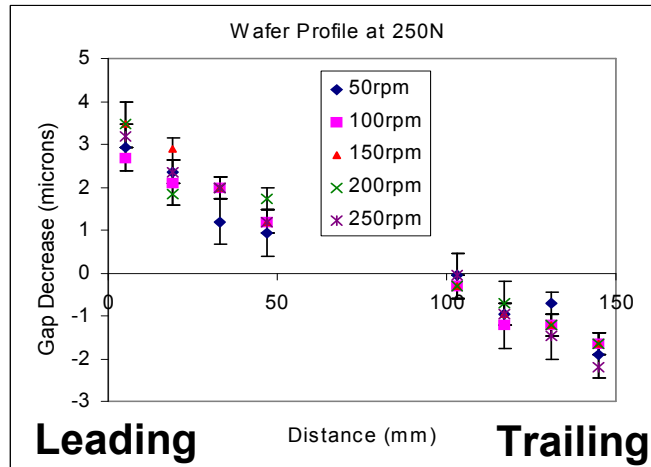
Experimental Layout

Wafer Carrier
Material: Stainless Steel

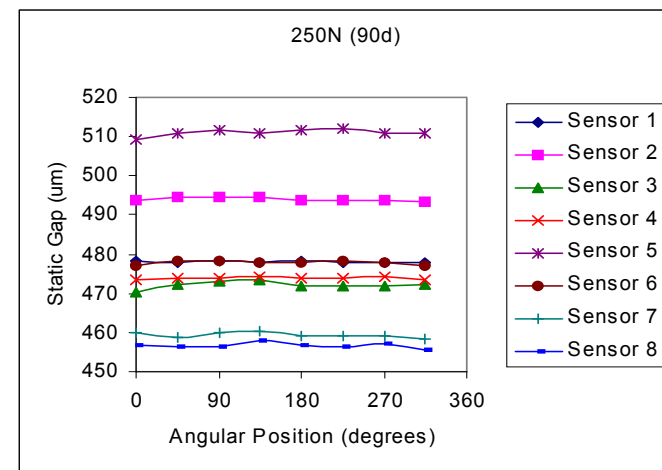
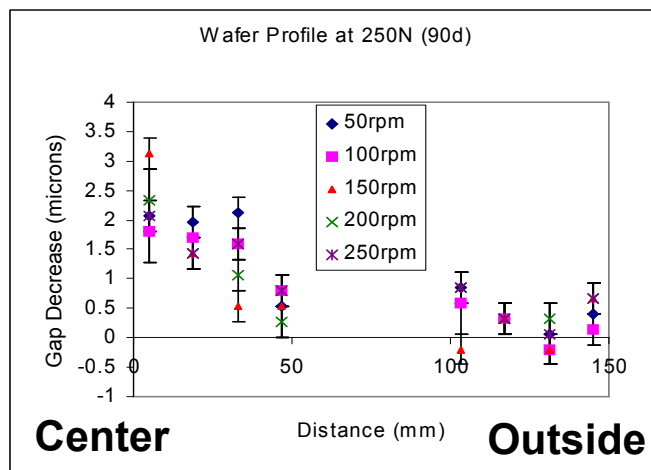


Dynamic Wafer Bending (250N)

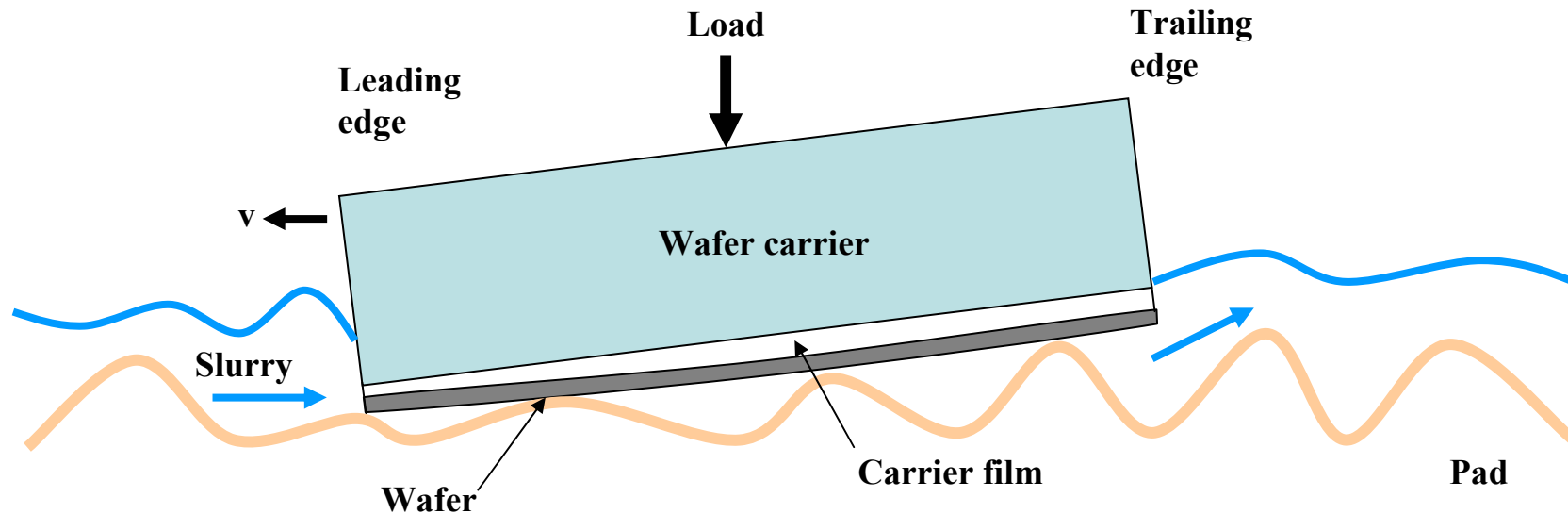
The gap decreases at the fixture leading edge ...



... and toward the pad center.



Geometry of the Problem with Wafer and Carrier Film



Fixture tilt ~ 50 μ m

Wafer tilt ~ 5 μ m

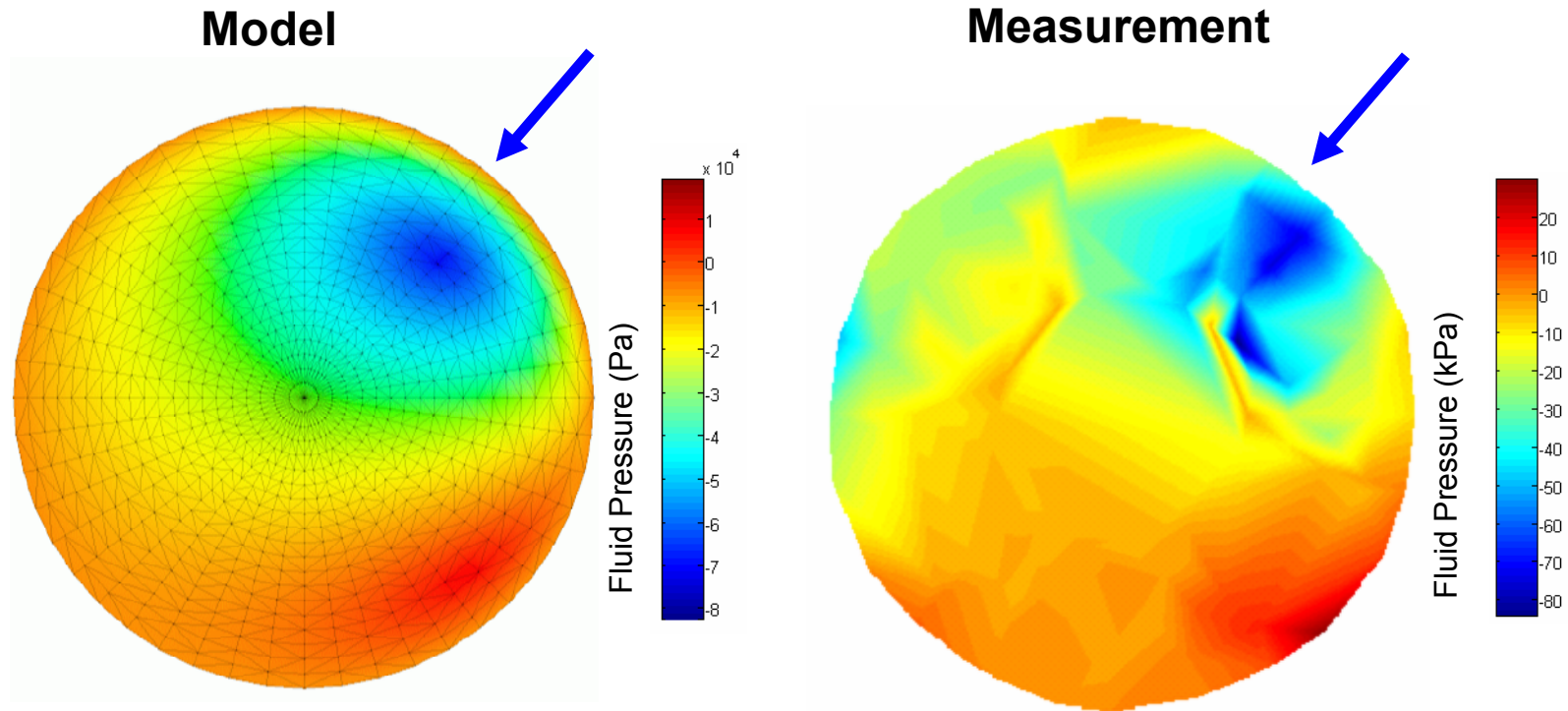
Wafer bow < 2 μ m

Conclusion: Fixture tilt dominates wafer tilt and bow. The fluid film is nearly the same for the plain fixture and for the fixture + wafer and carrier film.

Tilt-Suction Modeling

Fluid Model versus Measurement

Reynolds equation was used to calculate the fluid pressure given the measured wafer tilt and fly height. The result agrees well. Thus, Reynolds equation adequately describes the fluid dynamics.



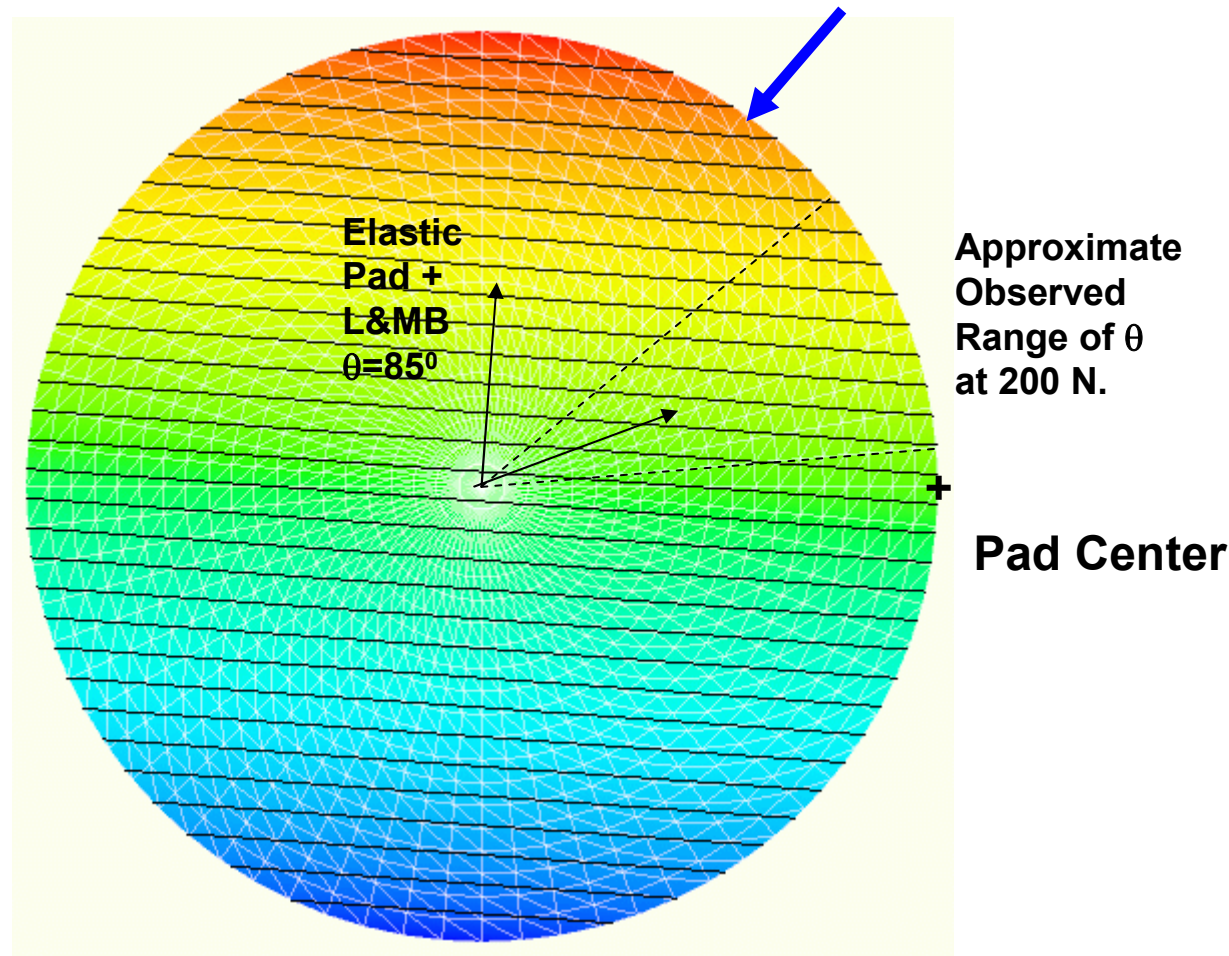
Reynolds Equation

$$\nabla \cdot \left(\frac{h^3}{12\mu} \nabla p_f \right) = \frac{1}{2} V \cdot \nabla h$$

Roughness corrections using pressure and shear flow factors are not needed.

Elastic Mechanical Model Predictions

If the pad is treated as an elastic material and load and moment balance are applied to the fixture, it is predicted to pitch down and to bank only slightly toward the pad center. This suggests that non-elastic properties of the pad are important in this case.



Conclusions

- Sub-ambient pressure occupies more than 70% of area under fixture
- As pad speed increases: elevation angle increases, azimuth angle decreases, the fly height increases, the sub-ambient pressure increases.
- The geometry of the gap is still maintained with actual CMP configuration involving the carrier film and the wafer
- Model based on geometric effects showed correlation with experimental data, confirming the validity of the Reynolds equation.

Acknowledgements

- Dupont-EKC
- Motorola
- CPC
- NSF
- SIMTech